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Evaluation of Water Mist Fire Extinguishing Systems For Flammable Liquid Storeroom Applications on US Army Watercraft

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A series of tests was conducted to evaluate the capability of water mist nozzles for extinguishing fires in flammable liquid storerooms. Three types of nozzles were evaluated: single fluid low pressure, single fluid high pressure and dual fluid (air/water) nozzles. The fire threats included: wood cribs, trash cans containing fuel-soaked rags, heptane pan fires and cascading fuel (heptane) fires. With a nominal 1.5 m (5.0 ft.) nozzle spacing, all of the nozzles could extinguish all of the fires except certain small [5.0 cm (2.0 in.)] heptane pan fires that were scattered throughout the compartment to evaluate the distribution patterns of the nozzles. However, water mist nozzles were found to have limitations with respect to horizontal obstructions.

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Evaluation of Water Mist Fire Extinguishing Systems for Flammable Liquid Storeroom Applications On US Army Watercraft

1.0 INTRODUCTION

The U.S. Army is investigating the use of water mist as a replacement for Halon 1301 total flooding systems currently installed in both flammable liquid storerooms and machinery spaces on Army watercraft. This evaluation is focussed on four Army ship designs that currently have onboard Halon 1301 fire extinguishing systems, namely: LCU 1600, LCU 2000, LSV and ROWPU Barge. An analysis of the fire threats in the flammable liquid storerooms of these ships is given in Appendix A. The present report addresses the results of the tests conducted to evaluate the use of water mist systems in flammable liquid storerooms on the four classes of ships mentioned above. The results of the machinery space tests will be covered in a separate report [1].

2.0 OBJECTIVES

The objective of this test series was to evaluate the feasibility of using a water mist fire extinguishing system as a replacement for the currently installed Halon 1301 total flooding system used in flammable liquid storerooms. This evaluation focussed primarily on the firefighting capabilities of the "state of the art" water mist technologies as applied to flammable liquid storerooms. A limited assessment of water mist system parameters (i.e., flow rates, pressures, nozzle spacings, etc.) was also conducted to optimize the firefighting capabilities of each system as well as to add robustness to the system's performance. The detailed test plan for the flammable liquid store rooms is given in reference [2]. At present, there are no internationally recognized fire test protocols for water mist systems in flammable liquid storerooms.

3.0 WATER MIST TECHNOLOGIES

3.1 Water Mist Overview

There are currently over twenty manufacturers of water mist hardware, some of which are commercially available as fire extinguishing systems while others are still under development or being used in other applications. For the purpose of more general discussion, these candidate systems break down into three distinct categories: single-fluid low-pressure, single-fluid high-pressure, and twin-fluid systems [3]. The droplet size distributions produced by similar technologies fall into discrete ranges. These ranges are shown as the volumetric mean droplet size (D_{V50}) in Fig. 1. All three system categories have been demonstrated as effective fire extinguishing technologies. A brief description of each of these categories is given in the following paragraphs.

3.1.1 Single-fluid Low-pressure Systems

Single-fluid low-pressure systems usually operate at or below 175 psi. Because of this relatively low operating pressure, these systems often utilize the same piping and materials as conventional sprinkler systems. This translates into a relatively simple, low cost system. The lower pressure nozzles also utilize larger orifice sizes to produce the same water flow rates. This increased orifice size can be an advantage in reducing the need for noncorrosive component materials and water supply filtration (to some extent).

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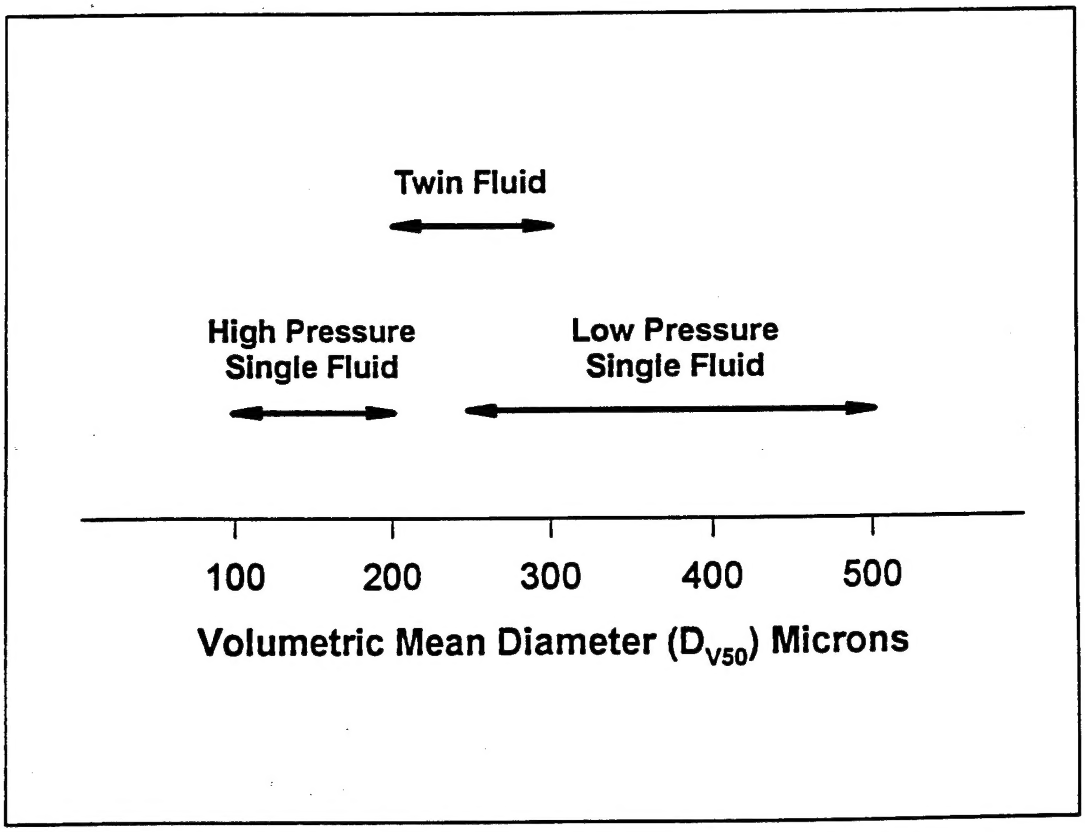


Fig. 1 - Drop size distribution ranges for the three water mist system categories

The disadvantages of these nozzles are larger average droplet sizes and higher water flow rates. The larger droplet sizes reduce the systems' capabilities against obstructed/shielded fires. The larger droplets have a higher terminal velocity than smaller droplets due to the mass of water contained in the droplet. This results in a high fall out rate of droplets from the mist. This fall out significantly reduces the amount of mist that effectively mixes throughout the space, predominately at higher elevations and around obstructions. The low pressure nozzles utilize higher flow rates in an attempt to negate these increased fall out losses.

3.1.2 Single-fluid High-pressure Systems

The single-fluid high-pressure systems, to date, have proven to be the most effective fire extinguishing mist system technology. As with the single-fluid low-pressure systems, these nozzles use a single-fluid (water or water plus an additive) but operate at pressures up to 200 bar (3000 psi). These high operating pressures provide an effective means of generating high concentrations of small droplets. The smaller droplet sizes exhibit more gaseous-like behavior and superior mixing characteristics. These characteristics increase the nozzles' capabilities against shielded/obstructed fires. The smaller droplets also have superior heat transfer characteristics to larger droplets due to a greater surface area to volume ratio. This allows the high pressure nozzles to utilize water more efficiently and consequently use less water.

The disadvantage of this technology is an increased system cost due to the need for high-pressure system components (i.e., pipes, fittings, valves, pumps, etc.). Power requirements associated with the high-pressure pumps may, in many cases, prove to be a severe disadvantage.

3.1.3 Twin-fluid Systems

Twin-fluid systems require two fluids, water and an atomizing fluid, both being supplied to the mist nozzle using separate piping networks. These nozzles utilize a high velocity stream of air or nitrogen to shear the water into small droplets. This process usually takes place in or directly in front of the nozzle. The advantage of this technology is that it produces large quantities of small water droplets at low operating pressures, usually less than 7 bar (100 psi). The disadvantage of this technology is the additional piping, storage volume, and associated cost of the atomizing fluid.

4.0 TEST DESCRIPTION

4.1 Storeroom Mock-up

The tests were conducted in a simulated flammable liquid storeroom consisting of a 3.0 x 3.0 x 2.4 m (10 x 10 x 8 ft) steel box with a single door (56 x 168 cm (22 x 66 in.)) located in the center of one wall as shown in Fig. 2. Two additional vents (one high forward and one low aft) were added to minimize the oxygen depletion in the closed compartment tests. The flammable liquid storeroom was simulated by adding a row of shelves along one wall of the compartment, a metal cabinet against the opposite wall, and a small table in the back of the space. This configuration represents a typical flammable liquid storeroom layout as identified during a ship survey conducted prior to the start of this project (Appendix A).

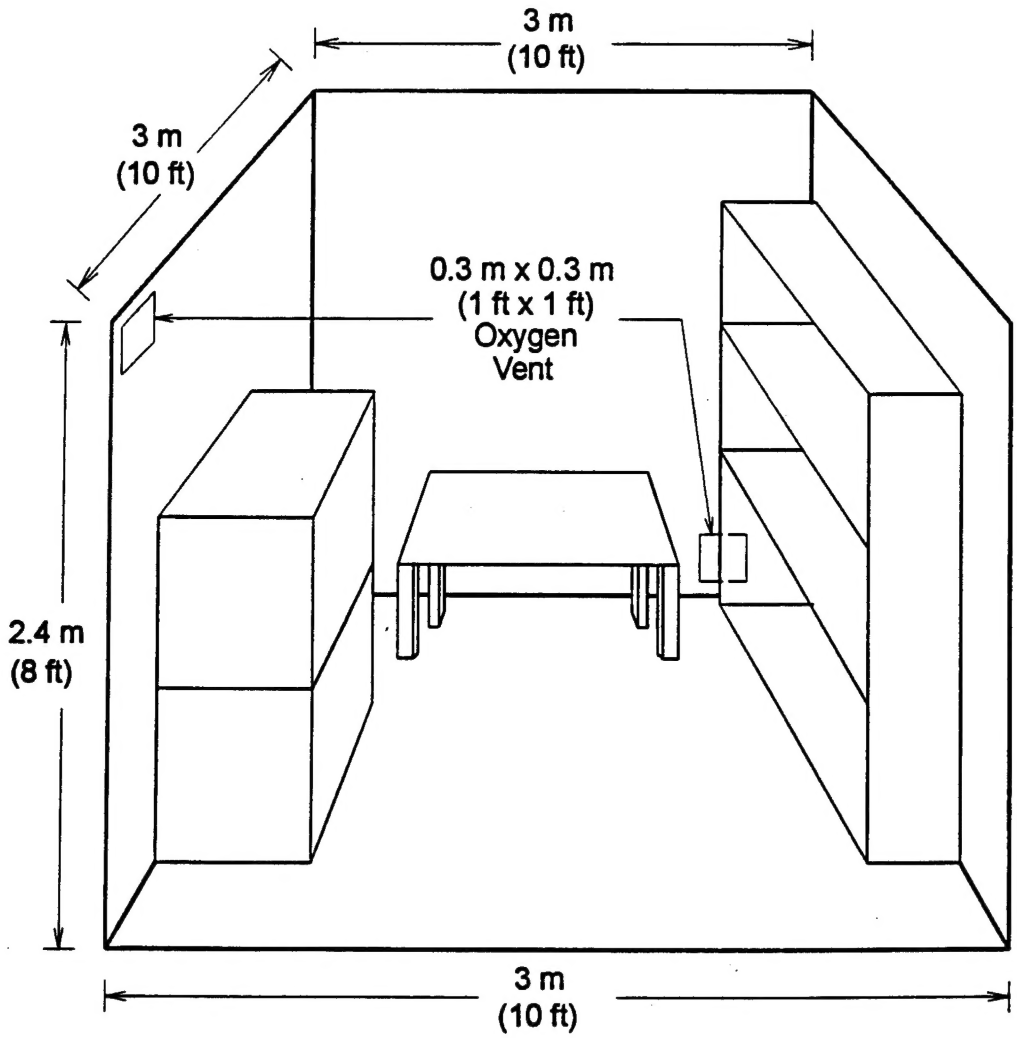


Fig. 2 - Mocked-up compartment

4.2 Instrumentation

The simulated storeroom was instrumented for air temperature, radiant and total heat flux, optical density, and typical fire gas species (O_2, CO, and CO_2) as shown in Fig. 3. The instruments were sampled at a rate of one scan every second for a duration of 10 minutes. A more detailed description of the instrumentation scheme is given in the following paragraphs.

4.2.1 Temperature Measurements

One thermocouple tree was installed in the center of the compartment for this test series. The tree consisted of eight type K inconel-sheathed thermocouples installed with 0.3 m (1.0 ft) spacings starting 0.15 m (6 in.) above the floor. The location of the tree is shown in Fig. 3. In addition, each fire was also instrumented with a thermocouple to determine extinguishment.

4.2.2 Gas Concentration Measurements

Carbon monoxide, carbon dioxide, and oxygen concentrations were measured in the center of the overhead of the space 0.15 m (6 in.) below the ceiling. Oxygen concentration measurements were also taken at the base of each fire.

4.2.3 Heat Flux Measurements

Both radiant and total heat flux were measured at the center of the aft bulkhead 1.0 m (3.2 ft) above the deck as shown in Fig. 3.

4.2.4 Optical Density

The optical density of the mist was measured across the corner of the compartment as shown in Fig. 3. These measurements were taken to determine the time required to achieve a maximum mist concentration in the space.

4.2.5 Video Cameras

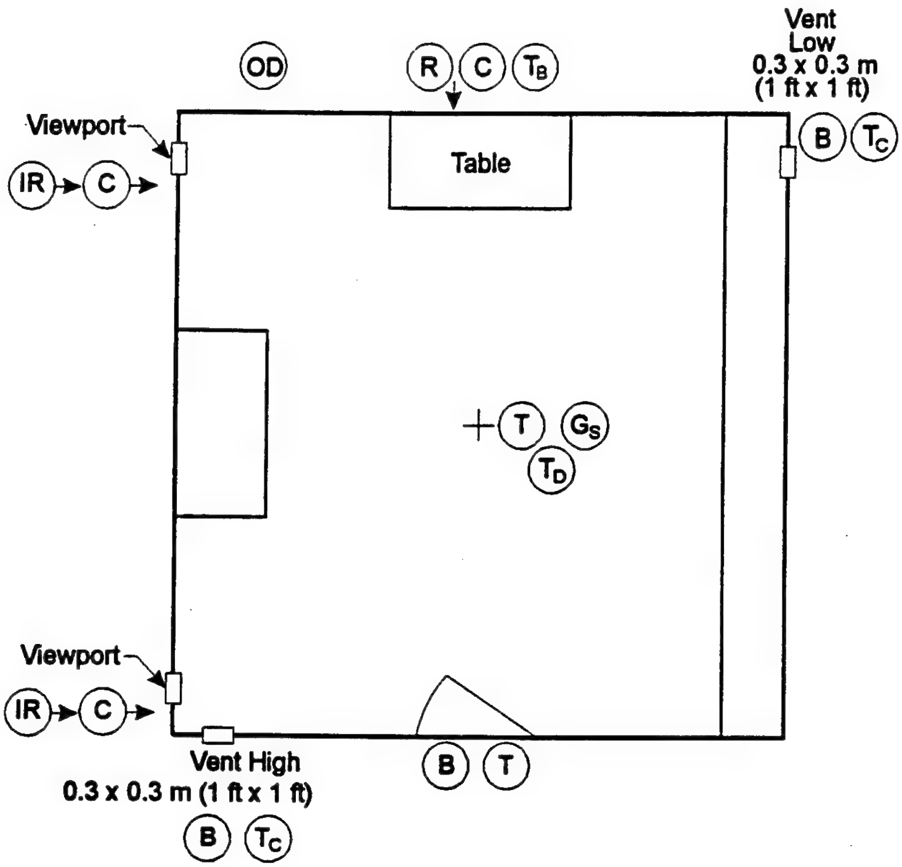
Each test/fire was videotaped using both a standard and an infrared video camera. The positions of each camera were varied depending on the fire location.

4.2.6 Mist System

The mist system was instrumented to measure both water flow rate and the operating pressure of the system. The water flow rate was measured using a paddle wheel flow meter installed in the supply to the system. The pressure was measured at one of the water mist nozzle locations.

4.3 Candidate Water Mist Nozzles

Six commercially available water mist fire extinguishing system nozzles and two generic off-the-shelf industrial spray nozzles, were selected for this evaluation. The candidate nozzles cover the range of available technologies from high and low-pressure single-fluid systems to twin-fluid systems. The generic nozzles were evaluated to identify any variations in performance between the "state of the art" water mist technologies and industrial water spray nozzles with similar droplet size distributions and water usage rates. In general, the commercially available nozzles were initially evaluated at the



T - Thermocouple Tree [0.3 m (1 ft) spacing starting @ 0.1 m (6 in)]

T_B - Thermocouple - Bulkhead

T_D - Thermocouple - Deck/Overhead

T_C - Thermocouple

B - Bidirectional Probe

C - Calorimeter

G_S - Gas Sampling (O2, CO, CO2)

R - Radiometer

IR → - IR Camera

C → - Video Camera

Fig. 3 - Instrumentation layout

manufacturer's recommended design parameters (i.e., pressure, flow rate, nozzle spacing, etc.). Due to the size of the test compartment, nozzles with a recommended 2.0 m (6.0 ft) spacing were evaluated with a 1.5 m (5.0 ft) nozzle spacing. When deemed necessary, modifications to the design were made in order to increase the overall performance of the system. The nozzle manufacturers evaluated during this test series include: Grinnell AquaMist, Kidde-Fenwal, Semco Marine, Marioff Hi-fog, Securiplex, and Spraying Systems. The candidate nozzles are shown in Fig. 4. A brief description of each nozzle is given in the following paragraphs.

4.3.1 Grinnell AquaMist Nozzle (AM-10)

The Grinnell AquaMist nozzle is a single-fluid, low-pressure nozzle which has a working pressure of 12 bar (175 psi) and is similar to a standard automatic sprinkler system in terms of design and operating principles. The AquaMist nozzle produces small droplets by impinging a water stream on a spherical deflector plate. The relatively low-pressure approach substitutes efficiency in producing small droplets (produces larger droplets than the high-pressure nozzles) for the cost and commercial advantages of using standard hardware (hardware used by conventional sprinkler systems). The AquaMist nozzle recommended for this evaluation (AM-10) has a nominal k-factor of 3.5 Lpm/bar^{½} (0.26 g.p.m./psi^{½}) and is typically installed with a 2.0 m (6.0 ft) nozzle spacing. This corresponds to a mist application rate (flow rate per unit area) of 4.46 Lpm/m^2 ((0.128 g.p.m./ft^2).

4.3.2 Kidde-Fenwal Water Mist Nozzle

The Kidde-Fenwal water mist nozzle is a low-pressure, single-fluid nozzle which has a working pressure of 12 bar (175 psi). It produces small droplets by impinging two water streams on one another. As with the Grinnell AquaMist nozzle, the low operating pressure sacrifices efficiency in producing small droplets for cost and commercial advantages of using standard sprinkler-type hardware. The Kidde-Fenwal nozzle has a nominal k-factor of 3.4 Lpm/bar^{½} (0.23 g.p.m./psi^{½}) and is typically installed with a 2.0 m (6.0 ft) nozzle spacing. This corresponds to a mist application rate of 3.5 Lpm/m^2 (0.1 g.p.m./ft^2).

4.3.3 Marioff Water Mist Nozzles

Marioff Hi-fog nozzles are high-pressure, single-fluid nozzles which have a working pressure of 200 bar (3000 psi), the highest pressure of any commercially available water mist nozzle. Although they are manufactured in a number of configurations, only two designs were tested during this evaluation. Both designs produce small droplets with high momentum. The first nozzle (Marioff's cabin compartment nozzle) contains four orifices, has a k-factor of 1.25 Lpm/bar^{½} (0.07 g.p.m./psi^{½}) and is typically installed with a 3.0 m (10 ft) nozzle spacing. The second design (Marioff's multipurpose nozzle) contains seven orifices, one central orifice surrounded by six perimeter orifices. The nozzle has a k-factor of 0.9 Lpm/bar^{½} (0.06 g.p.m./psi^{½}) and has a recommended nozzle spacing of 3.0 m (10 ft). These flow rates and spacings correspond to mist application rates of 1.2 Lpm/m^2 (0.034 g.p.m./ft^2) and 0.83 Lpm/m^2 (0.024 g.p.m./ft^2) respectively.

4.3.4 Semco Marine

The Semco Sem-Safe nozzle is a high-pressure, single-fluid nozzle which has a working pressure of 70 bar (1000 psi). It produces small droplets with moderate-high momentum. The Semco nozzle contains four orifices and has a nominal k-factor of 0.5 Lpm/bar^{½} (0.03 g.p.m./psi^{½}) and is typically installed with a 1.5 m (5 ft) nozzle spacing. This corresponds to a mist application rate of 1.4 Lpm/m^2 (0.04 g.p.m./ft^2).

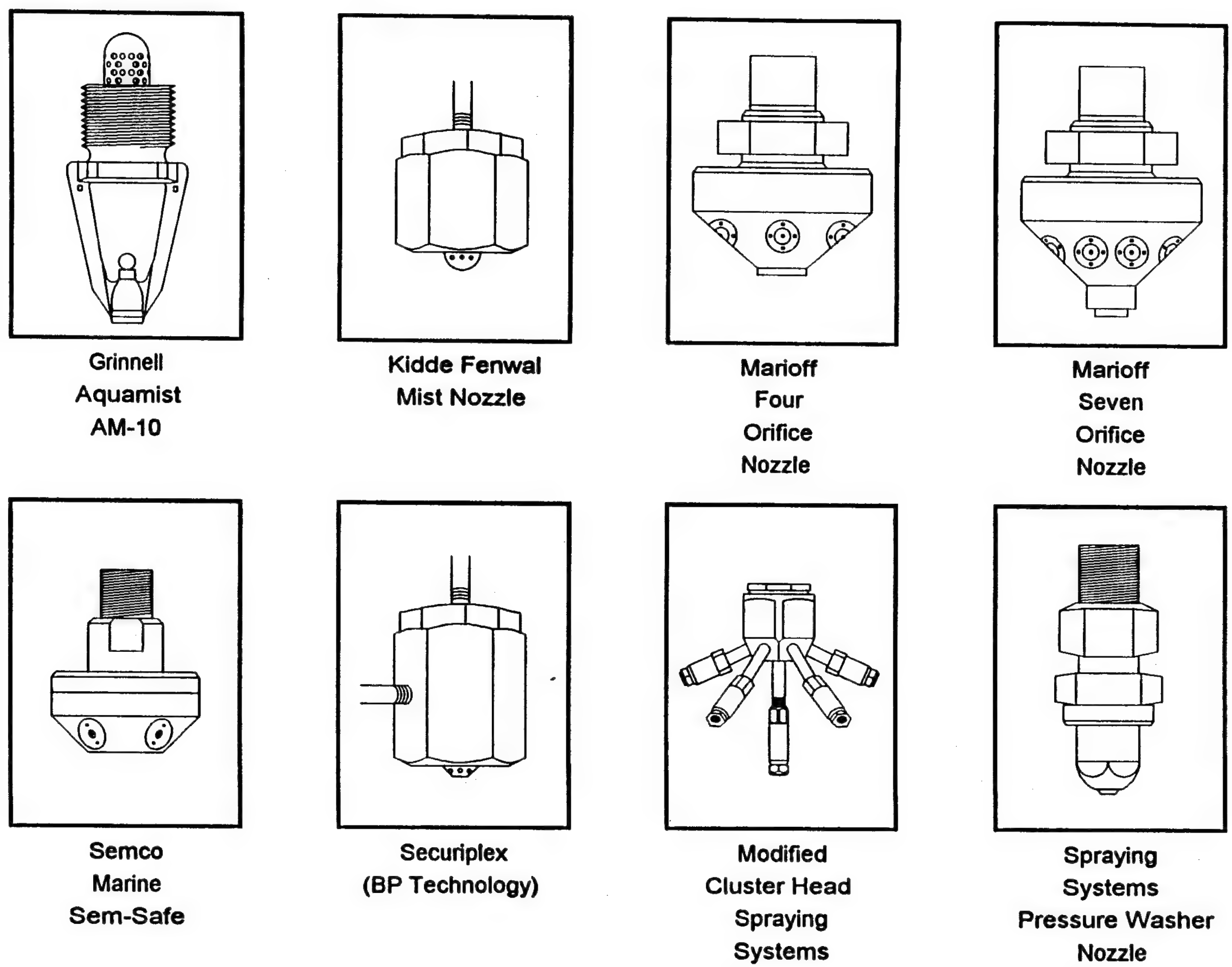


Fig. 4 - Selected nozzles

4.3.5 Securiplex System 2000

The Securiplex System 2000 nozzles are low-pressure, twin-fluid nozzles which use a secondary or atomizing fluid (air or nitrogen) to shear the water into small droplets. These nozzles operate at 5.5 bar (80 psi) for both fluids and produce medium-size droplets (200 microns) with moderate momentum. The nozzles have a k-factor of 4.5 Lpm/bar$^{1/2}$ (0.3 g.p.m./psi$^{1/2}$) and have a recommended nozzle spacing of 3.0 m (10 ft). This corresponds to an application rate of 0.95 Lpm/m^2 (0.027 g.p.m./ft^2).

4.3.6 Generic Nozzles

4.3.6.1 Modified Spraying Systems 7N Nozzle

The modified Spraying Systems nozzle is a single-fluid, high-pressure nozzle which was evaluated at a pressure of 70 bar (1000 psi). The nozzle is comprised of a Spraying Systems Model 7N nozzle body with seven model 1/4LN nozzle tips installed on 7.6 cm (3 in.) long brass nipples. The six nozzle tips installed around the perimeter are Model 1/4LN4, and the one in the center is a Model 1/4LN8. The purpose of the varying sizes of these nozzle tips is to produce droplets of different size and momentum: the perimeter nozzle tips produce small droplets with low momentum, and the center nozzle tip produces larger droplets with high momentum which serves to mix the mist throughout the space. With this configuration, the nozzle has a k factor of 1.20 Lpm/bar$^{1/2}$ (0.08 g.p.m./psi$^{1/2}$). These nozzles were installed with a 3.0 m (10 ft) nozzle spacing. This corresponds to a mist application rate of 0.91 Lpm/m^2 (0.026 g.p.m./ft^2).

4.3.6.2 Pressure Washer Nozzles

The final nozzle was an off-the-shelf pressure washer nozzle (T12W) also manufactured by Spraying Systems Inc. The nozzle is a single-fluid high-pressure nozzle that was evaluated at a pressure of 70 bar (1000 psi). The T12W nozzle has a k-factor of 0.45 Lpm/bar$^{1/2}$ (0.030 g.p.m./psi$^{1/2}$). These nozzles produce small droplets with high momentum. These nozzles were installed with a 1.8 m (5.0 ft) nozzle spacing. This corresponds to a mist application rate of 1.1 Lpm/m^2 (0.032 g.p.m./ft^2).

5.0 WATER MIST SYSTEM CONFIGURATION

The nozzles were installed in either of two configurations as described in the test plan [2]. The first configuration consisted of a single-nozzle installed in the center of the space, thus producing a nominal nozzle spacing of 3 m (10 ft). The second configuration consisted of four nozzles installed with nominally a 1.5 m (5 ft) spacing also shown in Fig. 5. The pipe network was constructed of 1.25 cm (0.5 in.) stainless steel tubing with single ferrule compression fittings. As constructed, the system had a working pressure of 200 bar (3000 psi). The pipe network was designed to allow an easy transition between the two system configurations. The system was supplied using two gasoline combustion engine driven pressure washers capable of providing a total flow rate of 54 Lpm (14 gpm) at pressures up to 200 bar (3000 psi). The system pressure was controlled using two pressure regulating valves (unloader valves) provided with each pressure washer. The pressure washers were supplied with potable water from the domestic water supply.

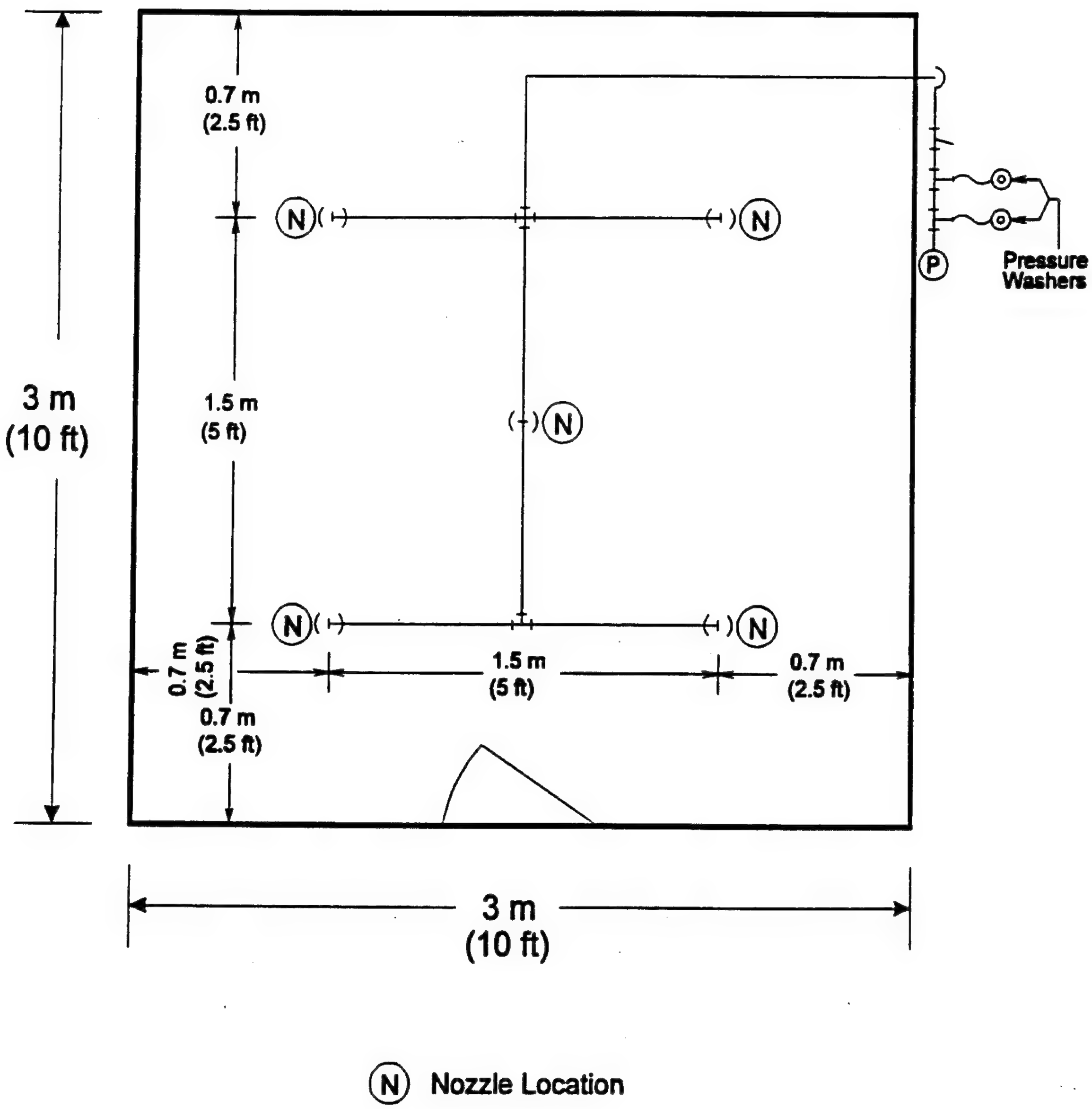


Fig. 5 - Pipe network with nozzle locations

6.0 FIRE SCENARIOS

The water mist systems were initially evaluated in a series of tests consisting of ten small heptane cup fires, referred to as "tell tales." These fires are not really representative of fires in flammable liquid storerooms; rather, they provide a means of mapping the distribution of water mist in the compartment. Accordingly, these fires were positioned at various locations throughout the space as shown in Figure 6. The tell tales measured 5.0 cm (2.0 in.) in diameter and were fueled with heptane to a depth of 2.54 cm (1.0 in.). This amount of fuel provides a burn duration on the order of 15 minutes. The tell tales were ignited and allowed to preburn for one minute prior to mist system activation. During each test, the mist system remained activated for a total of ten minutes. The extinguishment times for each tell tale were determined based on the temperatures measured directly above the fire and by visual observations.

It was initially intended to conduct the tell tale fire tests with the cabinet doors closed, but after a few scoping tests, the fires in the closed cabinet were confirmed to be too challenging for the candidate water mist technologies. For this reason, the remaining tell tale fire tests were conducted with the cabinet doors open. The tell tale fire tests were conducted in both open and closed compartments.

On completion of the tell tale fire tests, the systems were then evaluated against four representative fire scenarios. These fire scenarios were developed to represent the majority of the fire threats associated with flammable liquid storerooms as identified during two ship visits performed prior to the initiation of this test series (Appendix A). The four scenarios consisted of two Class A fire scenarios (a wood crib and a trash can fire) and two Class B fire scenarios (two pan fires and a cascading fuel fire). These fires are shown in Fig. 7. The Class A fires were conducted to evaluate the mist systems' ability to extinguish typical Class A threats associated with flammable liquid storerooms (i.e., tarps, rags, trash cans, etc.). The Class B fires are representative of fires involving flammable liquids in open containers as well as a variety of spill type fire scenarios. The majority of these fire tests were conducted in the compartment with the large door closed and the two small vents opened. A brief description of each fire scenario is given in the following paragraphs.

6.1 Wood Crib Fire Tests

The wood crib fire tests were conducted to evaluate the system's ability to extinguish relatively large, deep-seated Class A fires. The wood cribs used during these tests were constructed in accordance with Underwriters Laboratories Standard 1626 [4]. The cribs consisted of eight layers of four, 5 cm x 5 cm (nominal 2 in. x 2 in.), kiln-dried spruce members, each 30.5 cm (12 in.) in length. The finished cribs weighed between 5.5 and 5.9 kg (12 and 13 lb). The estimated heat release rate of each crib is nominally 250 kW. The cribs were positioned to provide a fair, but challenging, evaluation of both the single and four nozzle systems. Each crib was ignited using a small pan [15 cm x 15 cm (6 in. x 6 in.)] containing 200 ml of heptane and allowed to preburn for three minutes prior to a five-minute mist system activation. The tests were conducted with the large door closed and the air vents open.

6.2 Trash Can Fire Tests

The trash can fire tests were conducted to evaluate the water mist system's ability to extinguish a typical hazard found in flammable liquid storerooms: a trash can containing fuel soaked rags. The

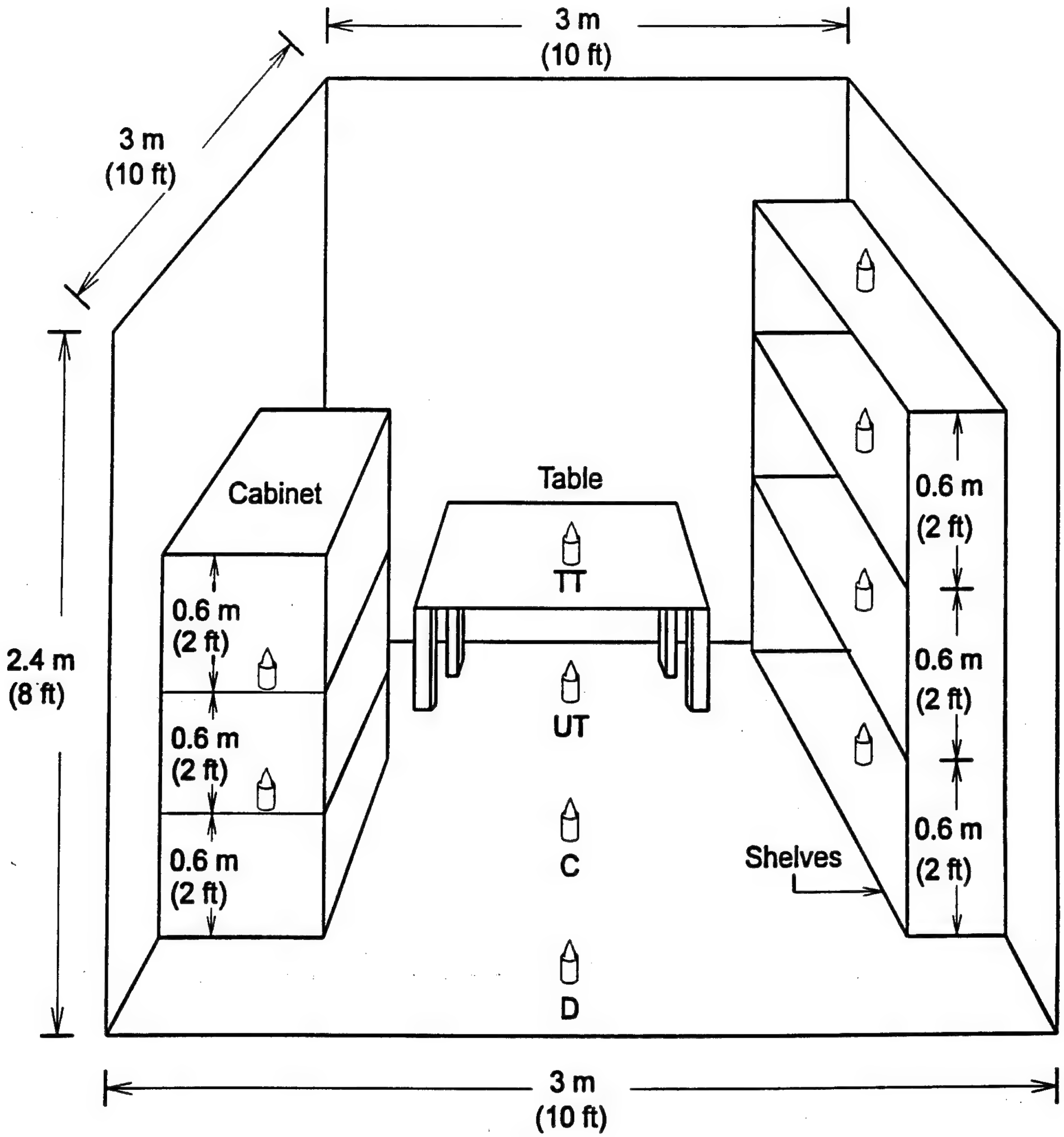


Fig. 6 - Tell tale fire locations

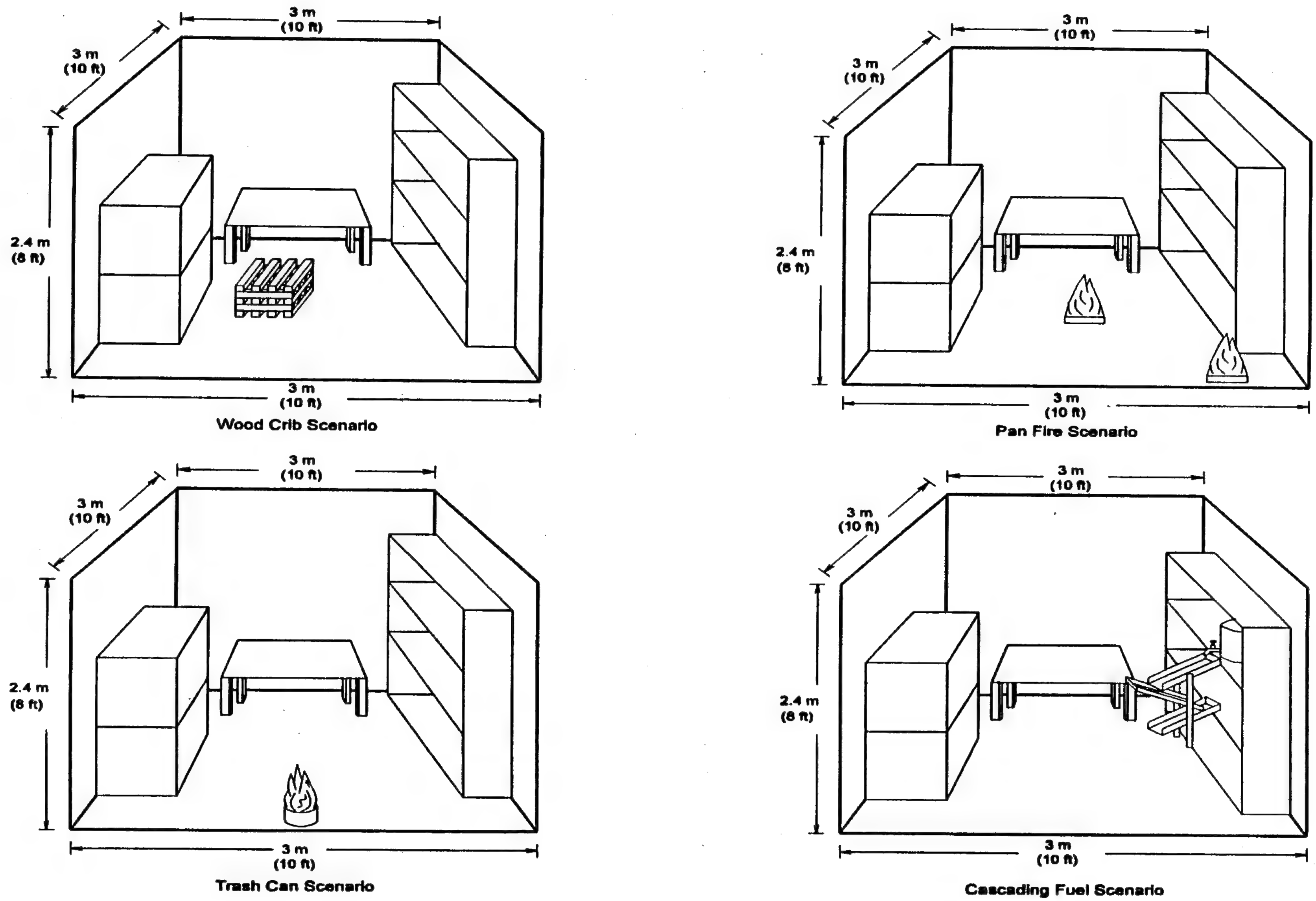


Fig. 7 - Fire scenarios

fire was produced by placing six, 30.5 x 61 cm (12 x 24 in.) cotton rags in a metal trash can measuring 41 cm (16 in.) in diameter by 46 cm (18 in.) tall. Two of the rags were placed such that half of the rag hung over the edge, outside of the trash can. The can was ignited using 200 ml of heptane poured over the rags. The heat release rate of this fire was estimated to be approximately 250 kW. The trash can was positioned against the center of one wall. This position represents a worst case location being either near or outside the spray pattern of the nozzle(s) for both the single and four nozzle configurations. The trash can was allowed to preburn for one minute prior to a two-minute mist system activation. The tests were conducted with the large door closed and air vents open.

6.3 Pan Fire Tests

The pan fire scenarios represents a realistic hazard associated with flammable liquid storerooms (coffee cans containing paint brushes soaking in turpentine or paint thinner). The pan fires consisted of two coffee cans containing heptane. The cans measured approximately 20 cm (8 in.) in diameter and 25 cm (10 in.) tall. Five centimeters (2 in.) of heptane was used in each can. The resulting 15 cm (6 in.) free board (pan lip) represents an extremely difficult pan fire and was considered more difficult to extinguish than the partially obstructed pan fire in Fire Scenario #2 of the test plan [2]. For this reason, the coffee cans were substituted for the pan fires of Fire Scenario #2. The horizontal-obstruction aspect of that scenario was partially addressed by the tell-tale fires which were located under the table, in a cabinet and on shelves - see Fig. 6. More extensive horizontal obstruction tests were not conducted since it was shown in the Navy program (5) that water mist systems are virtually ineffective if the horizontal obstruction extends more than 0.3 m (1 ft.) beyond the pan fire.

The two coffee cans were positioned in projected worst case locations (one in the center, a worst case position for the four-nozzle systems, and one in the corner, a worst case position for the single-nozzle systems). The fires, whch had a heat release rate of approximately 50 kw, were allowed to preburn for one minute prior to a ten-minute mist system activation. The tests were conducted with the large door closed and the air vents open.

6.4 Cascading Fuel Spill Fire Tests

The final evaluation was conducted against a cascading fuel spill scenario. The fire consisted of fuel (heptane) spilling from a 8.0 L (2.0 gal) storage container, down a series of channels, and into a 46 x 46 cm (18 x 18 in.) pan located on the floor of the space as shown in Fig. 8. This fire represents a worst case Class B fire comprised of both a two-dimensional pool fire and a three-dimensional flowing fuel fire. The hot metal surfaces of the fuel cascade also provided a substantial reignition source. The heat release rate of the fire was estimated to be nominally 350 kW (based on the flow rate of heptane). The fire was allowed to preburn for 30 seconds prior to a ten-minute mist system activation. The tests were conducted in both an open and closed compartment.

7.0 RESULTS AND DISCUSSION

7.1 Tell -Tale Fire Tests

The results of the tell tale fire test are listed in Table 1. As shown in this table, the two Marioff and two Spraying Systems nozzles exhibited superior performance by extinguishing 80 percent of the fires during these tests. The remaining nozzles, Grinnell AquaMist, Kidde-Fenwal, Securiplex, and Semco, were all only capable of extinguishing 60-70 percent of the fires during these tests. The superior performance exhibited by the two Marioff and two Spraying Systems nozzles was attributed to the nozzles' ability to produce larger quantities of small droplets with adequate momentum to mix the mist somewhat uniformly throughout the space. With the exception of the Semco Marine nozzle, the

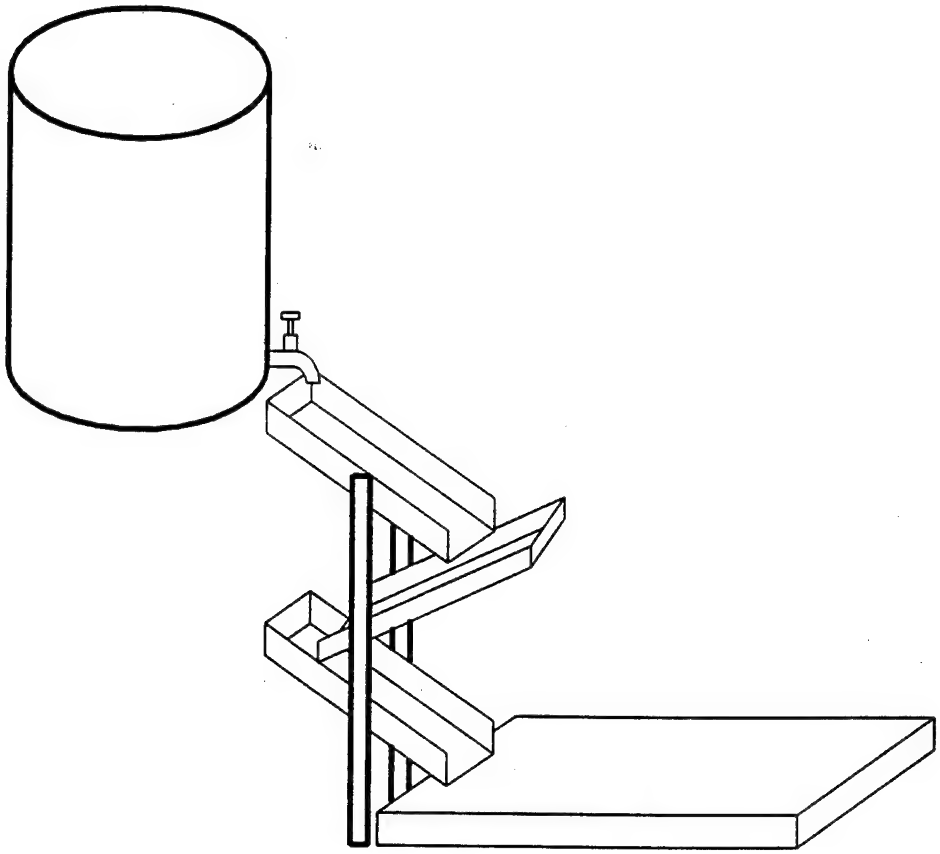


Fig. 8 - Fuel cascade configuration

remaining four nozzles all produce much larger droplet sizes with varying degrees of momentum. The Semco Marine nozzle produces small droplet sizes, but with less momentum and a substantially narrower spray pattern than the Marioff and Spraying Systems nozzles. The lower momentum and spray pattern characteristics of the Semco nozzles prevented adequate mixing of the mist throughout the space.

Table 1. Tell Tale Fire Test Summary

System Description	Pressure (bar (psi))	No. Nozzles	Flow (Lpm (gpm))	Application Rate (Lpm/m^2 (gpm/ft^2))	Percent Fires Extinguished
Grinnell's machinery space head	12 (175)	4	48.5 (12.8)	4.46 (0.128)	65
Kidde-Fenwal	12 (175)	4	37.9 (10.0)	3.5 (0.10)	70
Marioff's four-orifice nozzle	100 (1500)	1	12.9 (3.4)	1.20 (0.034)	80
Marioff's seven-orifice nozzle	100 (1500)	1	9.1 (2.4)	0.84 (0.024)	80
Semco's four-orifice nozzle	70 (1000)	4	15.1 (4.0)	1.40 (0.040)	60
Securiplex's 10 Lpm nozzle	4.5/4.5 (65/65)	1	10.0 (2.65)	0.95 (0.027)	65
Spraying Systems' modified cluster head	70 (1000)	1	10.0 (2.6)	0.91 (0.026)	80
Spraying Systems' pressure washer nozzles	70 (1000)	4	12.1 (3.2)	1.12 (0.032)	80

In general, the extinguishment characteristics measured during the tell tale fire tests illustrate the fires and fire locations that pose the greatest challenge to the various mist technologies. This is graphically represented in Figures 9A and 9B. The fires which pose the greatest challenge to the current technologies are the fires located high in the space: the two fires located at the 1.2 m (4 ft) elevation and the fire located at the 1.8 m (6 ft) elevation proved to be the most difficult. The reason for this is twofold. First, there is a discrete mist concentration gradient from the floor to the ceiling with the highest concentrations measured at the floor (Fig. 10) [6]. Second, if the mist system does not distribute adequate amounts of mist radially between the shelves, then, in order to extinguish these fires, the mist must be brought up from below, which is extremely difficult due to the presence of the shelves. During these tests, even the higher performance water mist nozzles (the single fluid, high pressure nozzles) were only capable of extinguishing one or two of the three fires high in the space.

The obstructed fire (the fire located under the table) also proved to be challenging for many of the candidate water mist systems. The nozzles which produce the largest quantities of small droplets (the high pressure, single fluid systems: Marioff, Spraying Systems, and Semco) were capable of consistently extinguishing this fire. The nozzles producing larger droplet sizes (the single fluid, low pressure systems: Grinnell and Kidde-Fenwal; the twin-fluid systems: Securiplex) showed limited success extinguishing the obstructed fire(s).

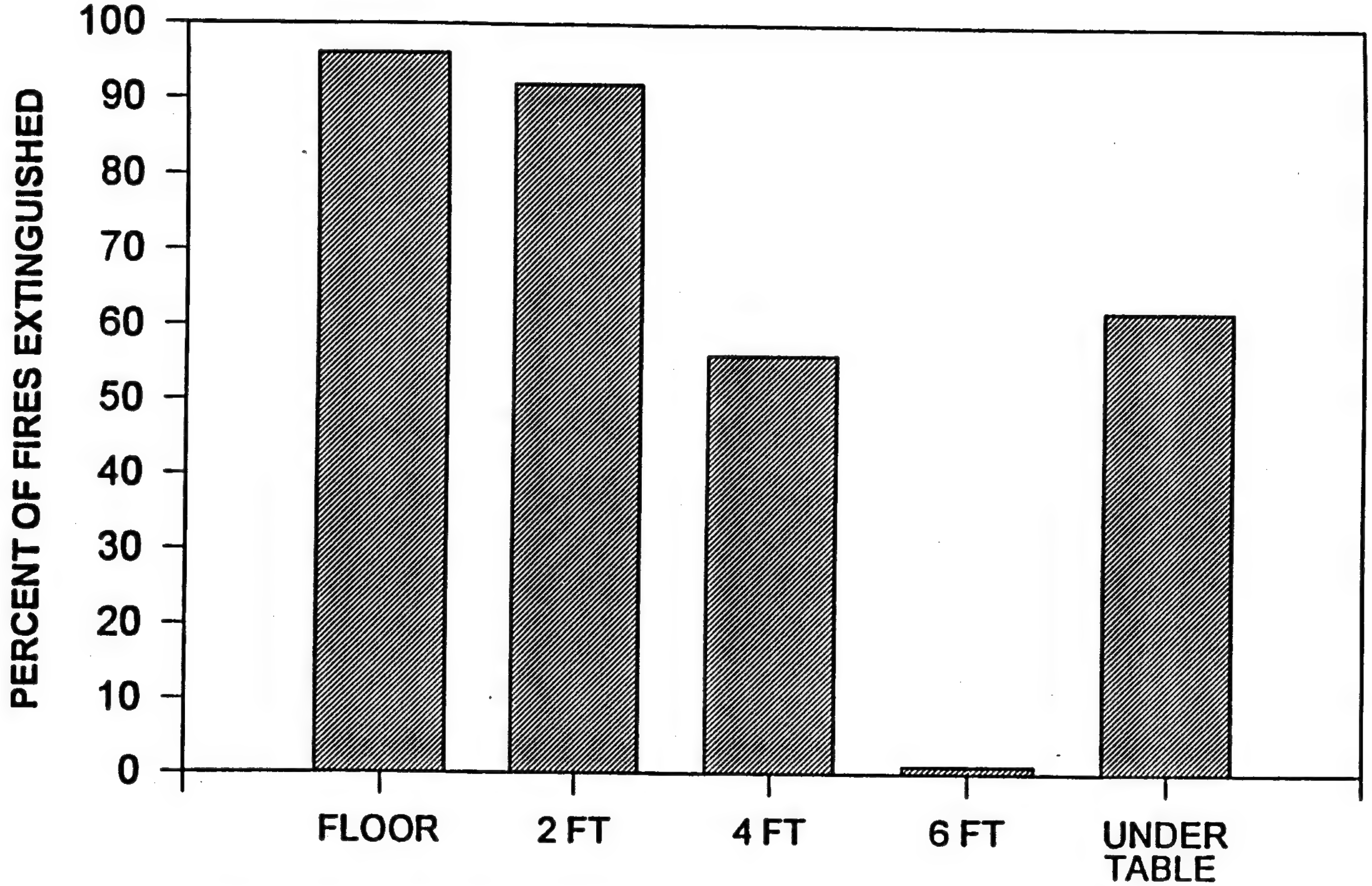


Fig. 9a - Tell tale extinguishment summary (averages for all nozzles)

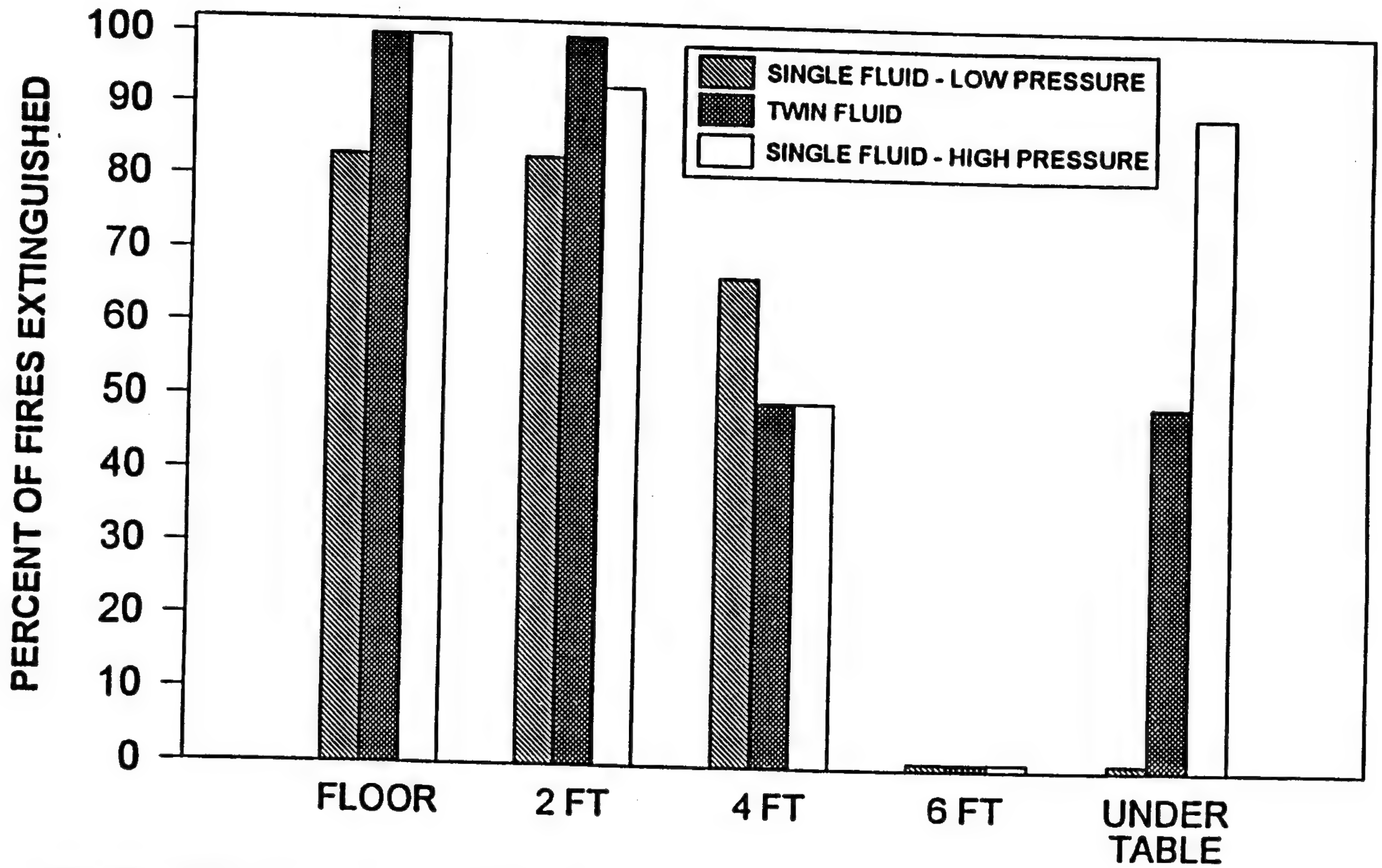


Fig. 9b - Tell tale extinguishment summary (averages for each system category)

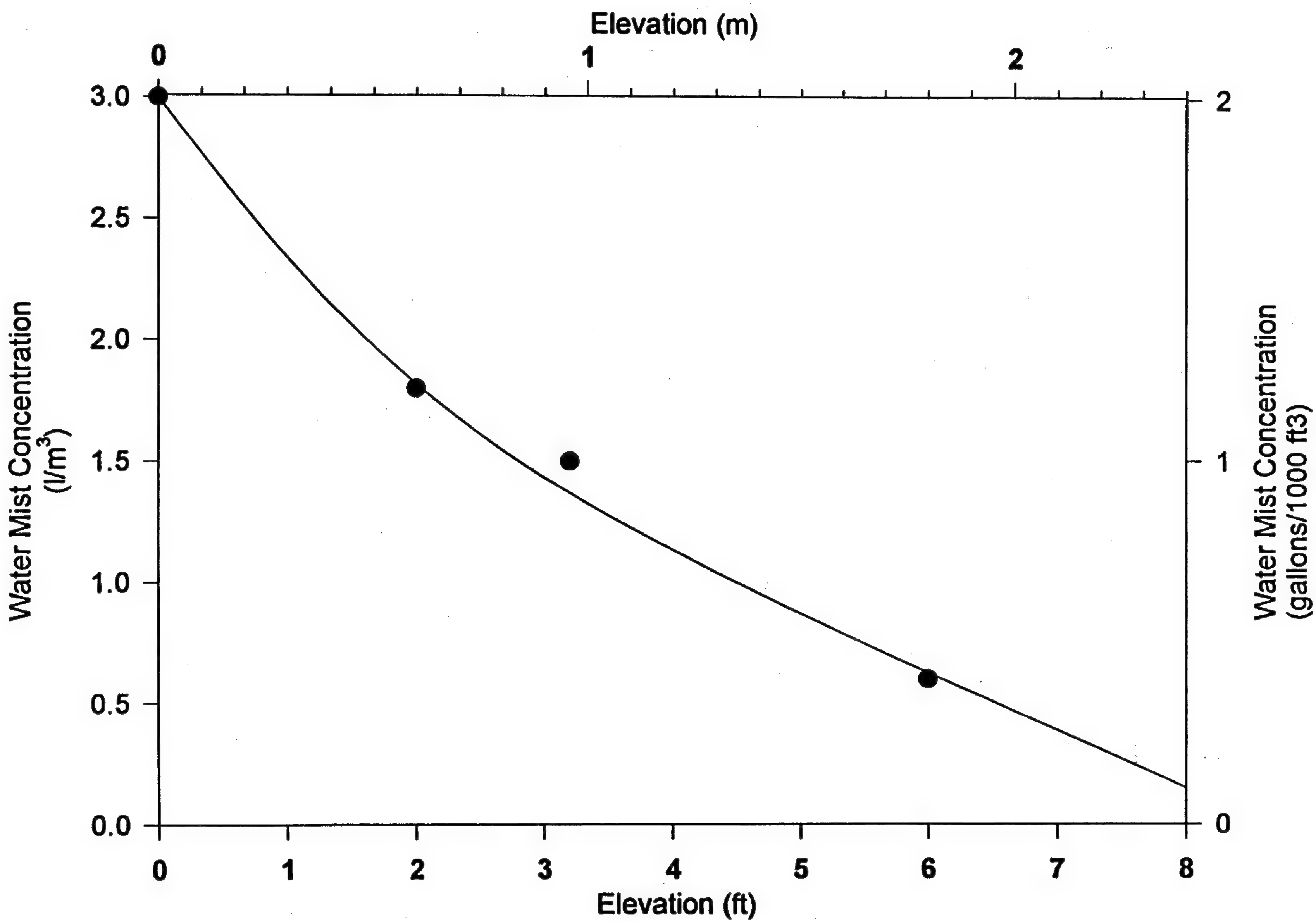


Fig. 10 - Water mist concentration gradient

7.2 Wood Crib Fire Tests

As stated previously, the wood crib fire tests were conducted to evaluate the water mist system's ability to extinguish relatively large, deep-seated Class A fires. The results of the wood crib tests are listed in Table 2. The firefighting capabilities were measured based as the time required to control the wood crib (no visible flames above the crib) and the time required to extinguish the fire (no glowing embers visible). As shown in Table 2, all seven nozzles were capable of controlling the fire, but only four were capable of extinguishing the crib. The four nozzles capable of extinguishing the wood crib were the Grinnell AquaMist and Kidde-Fenwal and two Spraying Systems nozzles. The Grinnell AquaMist and Kidde-Fenwal nozzles both controlled the fire within 30 seconds of mist activation with complete extinguishment occurring 30 seconds later (60 seconds total). The Spraying Systems nozzles required between 30 and 60 seconds for control with extinguishment occurring within 90 seconds of system activation. The two Spraying Systems nozzles were capable of extinguishing the crib with one-fourth of the water flow rate required by the Grinnell AquaMist and Kidde-Fenwal nozzles (~13 Lpm (~3.5 gpm) vs. ~50.0 Lpm (~13.0 gpm)). The remaining nozzles were capable of controlling the fires, but residual flaming was still observed inside of the crib after the five-minute discharge.

Table 2. Flammable Liquid Storage Results
(Unobstructed Wood Crib (1626 wood crib ≈ 250 kW) Tests, 3:00 Preburn)

System Description	Pressure (bar (psi))	No. Nozzles	Flow (Lpm (gpm))	Application Rate (Lpm/m^2 (gpm/ft^2))	Results (min:sec)	
					Controlled	Extinguished
Grinnell's machinery space head	12 (175)	4	48.5 (12.8)	4.46 (0.128)	0:15	0:45
Kidde-Fenwal	12 (175)	4	37.9 (10.0)	3.5 (0.10)	0:25	0:55
Marioff's four-orifice nozzle	100 (1500)	1	12.9 (3.4)	1.20 (0.034)	4:00	No
Marioff's seven-orifice nozzle	100 (1500)	1	9.1 (2.4)	0.84 (0.024)	2:00	No
Semco's four-orifice nozzle	70 (1000)	4	15.1 (4.0)	1.40 (0.040)	0:45	No
Securiplex's 10 Lpm nozzle	4.5/4.5 (65/65)	1	10.0 (2.65)	0.95 (0.027)	2:00	No
Spraying Systems' modified cluster head	70 (1000)	1	10.0 (2.6)	0.91 (0.026)	1:00	1:30
Spraying Systems' pressure washer nozzle	70 (1000)	4	12.1 (3.2)	1.12 (0.032)	0:30	1:15

The superior performance exhibited by the two single-fluid low-pressure nozzles (Grinnell AquaMist and Kidde-Fenwal) was attributed to the higher water flow rates and larger droplet sizes

characteristic of these nozzles. A primary mechanism for extinguishing a deep-seated Class A fire is surface wetting/cooling. Surface wetting is best achieved using either higher water flow rates and/or larger droplet sizes. The larger droplets contain adequate mass to penetrate the plume and strike the fuel surface. The smaller droplets can provide similar results if produced with sufficient momentum to reach the fuel surface. This was achieved by the two Spraying Systems nozzles during these tests. The remaining systems could not adequately wet the fuel surface to extinguish the fire.

7.3 Trash Can Fire Tests

The second fire hazard/scenario evaluated consisted of a trash can filled with heptane soaked cotton rags. This scenario represents a typical hazard found in flammable liquid storerooms. The results of the trash can fire tests are listed in Table 3. The firefighting performance was measured based on the percent of the surface area of rags in the trash can totally extinguished (no flaming or glowing embers). In all tests, the rags hanging outside of the trash can were completely extinguished. During the tests when more than 50 percent of the surface area was extinguished, no visible flaming was observed inside the trash can.

Table 3. Flammable Liquid Storage Results
(Unobstructed Trash Can Tests (trash can filled with heptane soaked rags))

System	Pressure (bar (psi))	No. Nozzles	Flow (Lpm (gpm))	Application Rate (Lpm/m^2 (gpm/ft^2))	Percent Extinguished
Grinnell's machinery space head	12 (175)	4	48.5 (12.8)	4.46 (0.128)	100
Kidde-Fenwal	12 (175)	4	37.9 (10.0)	3.5 (0.10)	100
Marioff's four-orifice nozzle	100 (1500)	1	12.9 (3.4)	1.20 (0.034)	40
Marioff's seven-orifice nozzle	100 (1500)	1	9.1 (2.4)	0.84 (0.024)	30
Semco's four-orifice nozzle	70 (1000)	4	15.1 (4.0)	1.40 (0.040)	90
Securiplex's 10 Lpm nozzle	4.5/4.5 (65/65)	1	10.0 (2.65)	0.95 (0.0265)	50
Spraying Systems' modified cluster head	70 (1000)	1	10.0 (2.6)	0.91 (0.026)	30
Spraying Systems' pressure washer nozzles	70 (1000)	4	12.1 (3.2)	1.12 (0.032)	80

As shown in Table 3, the overall performances varied dramatically, ranging from 30 to 100 percent of the rags extinguished. The single fluid, low pressure systems (Grinnell AquaMist and Kidde-Fenwal) both exhibited superior performance during these tests and were capable of completely extinguishing the trash can with a two-minute system activation time. This was primarily due to increased surface wetting as described in the wood crib fire test discussion. The Semco Sem-safe system extinguished 90 percent of the fire using one-third of the water flow rate [~15 Lpm (~4 gpm) vs. ~50 Lpm (~13 gpm)] required by the Grinnell AquaMist and Kidde-Fenwal systems. The remaining systems all produced mixed results. As a general observation, superior performance was

achieved by the systems that applied the mist vertically into the trash can. Interestingly, these systems were all using a 1.5 m (5.0 ft) nozzle spacing (four-nozzle systems). This illustrates the advantage of system designs that provide total spray pattern coverage of the protected area.

7.4 Pan Fire Tests

A series of tests was also conducted to evaluate the system's ability to extinguish two Class B pan fires in separate locations. The results of the pan fire tests are shown in Table 4. During these tests, only four mist systems were capable of extinguishing both pan fires. These systems were the Grinnell AquaMist system, the Kidde-Fenwal system, and both Marioff systems. The Grinnell AquaMist and Kidde-Fenwal systems were capable of extinguishing both fires within 40 seconds of mist system activation. The Marioff systems extinguished the center fire (the fire located under the nozzle) almost instantly, but required on the order of five minutes to extinguish the fire located in the corner of the room. The remaining four systems were capable of extinguishing fires located within the spray pattern of the nozzle but were unable to extinguish the fires located outside of the spray patterns. This again illustrates the advantage of total spray pattern coverage of the protected area. The 3.0 m (10 ft) nozzle spacing recommended for the high pressure, single fluid systems appears to be inadequate (too large) and should be re-evaluated by the manufacturers.

Table 4. Flammable Liquid Storage Results
(Unobstructed Pan Fire Tests)

System Description	Pressure (bar (psi))	No. Nozzles	Flow (Lpm (gpm))	Application Rate (Lpm/m^2 (gpm/ft^2))	Extinguishment Times (min:sec)	
					Pan #1 Corner Pan	Pan #2 Center Pan
Grinnell's machinery space head	12 (175)	4	48.5 (12.8)	4.46 (0.128)	0:35	0:37
Kidde-Fenwal	12 (175)	4	37.9 (10.0)	3.5 (0.10)	0:01	0:10
Marioff's four-orifice nozzle	100 (1500)	1	12.9 (3.4)	1.20 (0.034)	5:42	0:22
Marioff's seven-orifice nozzle	100 (1500)	1	9.1 (2.4)	0.84 (0.024)	4:19	0:01
Semco's four-orifice nozzle	70 (1000)	4	15.1 (4.0)	1.40 (0.04)	0:01	No
Securiplex's 10 Lpm nozzle	4.5/4.5 (65/65)	1	10.0 (2.65)	0.95 (0.027)	No	0:01
Spraying Systems' modified cluster head	70 (1000)	1	10.0 (2.6)	0.91 (0.026)	No	0:01
Spraying Systems' pressure washer nozzles	70 (1000)	4	12.1 (3.2)	1.12 (0.032)	0:01	No

7.5 Cascading Fuel Fire Tests

The final series of tests was conducted against a cascading fuel spill scenario. This fire represents a worst case Class B fire comprised of both a two-dimensional pool fire and a three-dimensional running fuel fire. The results of the cascading fuel fire tests are shown in Table 5. As shown in Table 5, all of the systems were capable of extinguishing the cascading fuel fires in both open and closed compartments. The Marioff four-orifice cabin nozzle exhibited the best performance, extinguishing the cascading fuel fire in both the open and closed compartment within 40 seconds of mist system activation. The extinguishment times produced by the other systems ranged from one to five minutes. As a whole, the faster extinguishment times were produced by the single-fluid high-pressure systems. The smaller droplets and higher momentum produced by these systems appear to increase the system's capabilities against this type of fire. Consequently, the larger droplet systems (single fluid, low pressure, and twin fluid systems) produced the longest extinguishment times. The extinguishment times measured in the closed compartment tests were nominally one minute faster than those conducted in the open compartment. This suggests that these water mist systems are less affected by ventilation conditions than originally anticipated and may be applied to open spaces in some applications. However, additional work is required to identify the limiting parameters in such applications.

Table 5. Flammable Liquid Storage Results
(Unobstructed Fuel (Heptane) Cascade Tests ≈ 350 kW)

System	Pressure (bar (psi))	No. Nozzles	Flow (Lpm (gpm))	Application Rate (Lpm/m^2 (gpm/ft^2))	Vent (open/ closed)	Extinguishment Time (min:sec)
Grinnell's machinery space head	12 (175) 12 (175)	4 4	48.5 (12.8) 48.5 (12.8)	4.46 (0.128) 4.46 (0.128)	O C	4:20 4:30
Kidde-Fenwal	12 (175) 12 (175)	4 4	37.9 (10.0) 37.9 (10.0)	3.5 (0.10) 3.5 (0.10)	O C	5:10 4:30
Marioff's four-orifice nozzle	100 (1500) 100 (1500)	1 1	12.9 (3.4) 12.9 (3.4)	1.20 (0.034) 1.20 (0.034)	O C	0:35 0:15
Marioff's seven-orifice nozzle	100 (1500) 100 (1500)	1 1	9.1 (2.4) 9.1 (2.4)	0.84 (0.024) 0.84 (0.024)	O C	1:15 0:20
Semco's four-orifice nozzle	70 (1000) 70 (1000)	4 4	15.1 (4.0) 15.1 (4.0)	1.40 (0.04) 1.40 (0.04)	O C	5:20 3:30
Securiplex's 10 Lpm nozzle	4.5/4.5 (65/65) 4.5/4.5 (65/65)	1 1	10.0 (2.65) 10.0 (2.65)	0.95 (0.027) 0.95 (0.027)	O C	2:00 1:10
Spraying Systems' modified cluster head	70 (1000) 70 (1000)	1 1	10.0 (2.6) 10.0 (2.6)	0.91 (0.026) 0.91 (0.026)	O C	2:35 1:30
Spraying Systems' pressure washer nozzles	70 (1000) 70 (1000)	4 4	12.1 (3.2) 12.1 (3.2)	1.12 (0.032) 1.12 (0.032)	O C	3:15 2:30

8.0 SUMMARY

A summary of the flammable liquid storeroom fire tests is given in Table 6. The last column in the table shows a calculated relative rating for each nozzle/system based on its performance in each of the five fire tested scenarios. The fire performance rating of each system was based on the following: the distribution test rating is the percentage of tell tale fires extinguished by each system, the rating shown for the wood crib fire tests corresponds to a score of 50 for fire control and 100 for complete extinguishment, the trash can fire tests were scored according to the percentage of fuel surface area completely extinguished, each of the two pool fires was worth a value of 50 for successful extinguishment and the cascading fuel fire tests were given values of 100 for extinguishment and zero for no extinguishment. As shown in Table 6, the two low pressure, single-fluid systems (Grinnell AquaMist and Kidde-Fenwal) exhibited superior results throughout this test series (ratings of 93 and 94). The superior performance of these systems was attributed to both their relatively high water flow rates, 3 to 5 times greater than the other nozzles, and their superior capabilities against deep-seated Class A fires. The low pressure, single-fluid systems produce larger droplet sizes, increasing their capability against Class A fires due to surface wetting effects. Unfortunately, the larger droplet sizes appear to reduce the system's ability to extinguish shielded/obstructed fires as shown by the lower number of fires extinguished during the tell tale fire tests.

Table 6. Flammable Liquid Storeroom Tests – Summary of Percent of Fires Extinguished and Ratings

Description	System	Flow (Lpm (gpm))	Application Rate Lpm/m^2 (gpm/ft^2)	Percent of Fire Extinguished					Rating
				Distribution Tests (Tell Tales)	Wood Crib Fire Tests	Trash Can Fire Tests	Large Pool Fire Tests	Cascading Fuel Fire Tests	
Grinnell's machinery space head	G-AM10	48.5 (12.8)	4.46 (0.128)	65	100	100	100	100	93
Kidde-Fenwal	KF-4	37.9 (10.0)	3.5 (0.10)	70	100	100	100	100	94
Marioff's four-orifice nozzle	M-4	12.9 (3.4)	1.20 (0.034)	80	50	40	100	100	74
Marioff's seven-orifice nozzle	M-7	9.1 (2.4)	0.84 (0.024)	80	50	30	100	100	72
Semco's four-orifice nozzle	Sem-4	15.1 (4.0)	1.40 (0.040)	60	50	90	50	100	70
Securiplex's 10 Lpm nozzle	SEC-10	10.0 (2.65)	0.95 (0.027)	65	50	50	50	100	63
Spraying Systems' modified cluster head	SS-7N4	10.0 (2.6)	0.91 (0.026)	80	100	60	50	100	78
Spraying Systems' pressure washer nozzles	SS-T12W	12.1 (3.2)	1.12 (0.032)	80	100	80	50	100	82

Four of the five high-pressure, single-fluid systems (two Marioff and two Spraying Systems) also performed quite well during this evaluation. These high-pressure, single-fluid systems discharge approximately one-third of the quantity of the water required by the two low-pressure, single-fluid systems. The smaller average droplet sizes, characteristic of these systems, increase the system's capabilities against shielded/obstructed fires, but decrease their capabilities against deep-seated Class A fires. This is evident by the higher percentage of fires extinguished during the tell tale fire tests and the systems' inability to completely extinguish the Class A fires. The remaining two systems, Semco (a high pressure, single fluid system) and Securiplex (a twin fluid system), both exhibited varying degrees of success but overall performed inferior to the previously mentioned six systems.

The manufacturers recommended nozzle spacing was also identified as a predominant variable in the overall system performance (or lack thereof). Three of the four high-pressure systems were installed with nominal 3.0 m (10 ft) nozzle spacings (per manufacturers' recommendations). A tighter nozzle spacing will decrease the holes in the spray pattern coverage, increase the systems' application rate, and may increase the system's capabilities. These results also suggest that a single-nozzle installation is a worst case system configuration due to mist spray pattern interactions with the walls of the enclosure (wall losses). In a single-nozzle configuration, any overspray from an individual nozzle is lost to the walls as opposed to being lost into an adjacent nozzle zone/spray pattern. One could argue that any mist lost horizontally from a nozzle spray pattern is regained by contributions from adjacent nozzles for multiple nozzle configurations. This would suggest that the proper configuration to evaluate this technology requires a minimum of two nozzle spacings in each direction (four nozzles total) with the fire(s) situated somewhere between the four nozzles. Emphasis also needs to be placed on the distances that nozzles are installed away from walls and corners.

9.0 ADDITIONAL TESTS

To confirm the previous discussion on the number and spacing of nozzles, additional tests were conducted with the Marioff four-orifice nozzles, the modified Spraying Systems cluster nozzles, and the Securiplex nozzles. During these tests, the Marioff, Modified Spraying Systems and Securiplex nozzles were installed using the same nominal 1.5 m (5.0 ft) nozzle spacing as was used for the more successful Grinnell and Kidde-Fenwal nozzles. However, for the tests with the modified Spraying Systems nozzles, a lower flow rate nozzle was selected (SS-7N2 versus SS-7N4). The reduced flow rate nozzle flowed approximately 5.2 Lpm (1.33 gpm) at 70 bar (1000 psi), producing an application rate of 2.2 Lpm/m^2 (0.053 gpm/ft^2). The Securiplex 5.0 Lpm (1.2 gpm) nozzle was also substituted for the 10 Lpm (2.6 gpm) nozzle during this evaluation, thus producing roughly the same application rate. The Marioff four-orifice nozzles flow 13.2 Lpm (3.4 gpm) at 100 bar (1500 psi), thus producing an application rate of 5.9 Lpm/m^2 (0.136 gal/ft^2). The above three systems were each re-evaluated against the original five fire scenarios.

The results of these additional tests are summarized in Table 7 along with the results of the original tests conducted with the low-pressure, single-fluid systems (Grinnell AquaMist and Kidde-Fenwal systems). The data show that when the Marioff, Spraying Systems and Securiplex nozzles are installed using the same nozzle spacing as the Grinnell and Kidde-Fenwal nozzles, similar results are obained. During these tests, all five four-nozzle systems were capable of extinguishing well over 90 percent of the test fires evaluated in this test series. The results were such that a clear superior system could not be determined. However, both the modified Spraying Systems nozzles and the Securiplex nozzles were capable of producing comparable, if not superior results, with approximately one-half the water required by the other systems.

Table 7. Flammable Liquid Storeroom Tests - Additional Tests, Percent of Fires Extinguished and Ratings

Description	Application Rate	Total Flow	System	Distribution Tests (Tell Tales)	Wood Crib Fire Tests	Trash Can Fire Tests	Large Pool Fire Tests	Cascading Fuel Fire Tests	Rating
	Lpm (gpm)	Lpm/m² (gpm/ft²)							
Grinnell's machinery space head	48.5 (12.8)	4.46 (0.128)	G-AM10	65	100	100	100	100	93
Kidde-Fenwal	37.9 (10.0)	3.5 0.100)	KF-4	70	100	100	100	100	94
Marioff's four-orifice nozzle	51.5 (13.6)	4.70 (0.136)	M-4	90	100	100	100	100	98
Securiplex's 5 Lpm nozzle	20.1 (5.3)	1.86 (0.053)	SEC-5	75	100	100	100	100	95
Spraying Systems' modified cluster head	20.1 (5.3)	1.86 (0.053)	SS-7N2	90	100	100	100	100	98

10.0 CONCLUSIONS

The water mist nozzles evaluated during this experimental program have demonstrated the potential of using water mist to replace Halon 1301 in Army watercraft flammable liquid storeroom applications. In these tests, the firefighting capabilities of the "state-of-the-art" water mist technologies were determined to lie somewhere between a Halon 1301 total flooding system and a conventional sprinkler system. These water mist nozzles were capable of extinguishing over 90 percent of the test fire scenarios evaluated during this experimental program. Many of these fires would be too difficult for conventional sprinkler systems to extinguish. On the other hand, the extinguishment times recorded for these water mist systems were substantially longer than would be expected using either Halon 1301 or a comparable gaseous system (i.e., 100-200 seconds for water mist versus 10-20 seconds for Halon 1301). In addition, water mist systems were found to have limitations with respect to horizontal obstructions. In open spaces, water mist may have superior firefighting capabilities to the other gaseous systems.

The results of these tests suggest that water mist technologies can provide adequate protection of flammable liquid storerooms that lie within the realm of parameters evaluated during this test program; namely, relatively smaller spaces (less that 30 m^2 (300 ft^2) of floor area) with standard ceiling heights (~2.4 m (8 ft)) and somewhat simple geometries. These parameters are consistent with those observed in Army watercraft flammable liquid storage space applications. It should be noted that flammable liquid storerooms on Army watercraft are generally smaller than comparable spaces on Navy ships. Consequently, this investigation provides little, if any, information on the ability of water mist to protect the larger, Navy flammable liquid storerooms.

Some of these unresolved conventional flammable liquid storeroom characteristics are listed as follows:

- spaces with high ceilings,
- spaces with complex geometries,
- areas of high rack storage,
- flammable liquids stored in plastic containers,
- storage of plastic commodities, and
- other types of fuels, etc.

Additionally, this study has shown that the firefighting capability of a water mist system is highly dependent on nozzle spacing. For example, the firefighting capabilities of three candidate nozzles were dramatically improved by reducing the nozzle spacing. The measurable improvement was observed in the systems' capabilities against both Class A and shielded fires. All eight systems evaluated during this program were selected for further evaluation in the full-scale machinery space tests.

11.0 REFERENCES

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APPENDIX A

Fire Hazard Analysis of Flammable Liquid Storage Rooms on Army Watercraft

INTRODUCTION

The Naval Research Laboratory is exploring the feasibility of employing water mist fire extinguishing systems for machinery space and flammable liquid storage rooms on Army Watercraft under Department of Transportation reimbursable Agreement DTRS-57-94-X-0066. Task 2 of the Project Work Plan for that contract includes an analysis of Army watercraft fire hazards, ignition scenarios, and physical attributes of the hazard areas. This report describes the analysis of the flammable liquid storage rooms; machinery spaces are covered in a separate report.

FIELD INVESTIGATIONS

In order to establish the fire hazards, compartment configurations, and potential testing requirements, an on-site field investigation was conducted at Fort Eustis, Virginia, on June 6-7, 1994. A vessel representing each of the four major ship classes (LCU 2000 series, LCU 1600 series, LSV, and ROWPU Barge) containing Halon 1301 fire suppression systems was investigated. Each area that contained a Halon 1301 fire suppression system was documented for the following:

- overall interior dimensions;
- openings;
- special conditions;
- wall coverings;
- locations, dimensions, and construction of obstructions;
- locations and magnitude of potential hazards;
- existing fire suppression system scheme;
- storage area of Halon 1301 cylinders; and
- initial evaluation of potential cylinder and/or pump storage for the water mist systems.

The vessels visited were as follows:

- The LCU 2003 - "MACON,"
- The LCU 1675,
- The LSV - "General George S. Besson, Jr.," and
- The ROWPU Barge.

The results of the field investigation are summarized in Tables A1-A3 and the accompanying figures (Figs. A1-A3). The major fuels' sources identified included a variety of combustible liquids, such as marine diesel fuel, engine oil, hydraulic oil, paint and paint thinner, and miscellaneous combustibles, such as cardboard boxes, oil soaked rags, wood pallets, etc.

The compartment sizes and total fuel loading varied widely from vessel to vessel. However, no compartment investigated exceeded a total height requirement of 4.5 m (15 ft).

Table A1. Survey Summary Chart

Vessel: LCU 2003

Compartment: Flammable Liquid Storage Room - See Figure

Room dimensions:

Length:	35'-0" long side of triangular room
Width:	12'-4"
Main compartment height:	7'-10"
Bilge depth:	N/A
Overall height:	7'-10"

Potential hazards

1. Flammable liquids: Paints in closed and open 1 and 5 gallon cans; paint thinners; stripping agents; linseed oil.
2. Combustibles: Rollers; brushes; joint tape; rags; cardboard boxes; wood ladders, cable spools, platform, shelving; life saving devices.
3. Diesel fuel: Portable diesel generator leak - potentially ½ gallon.
4. Engine oil: Portable diesel generator leak - potentially 1 quart.

Openings

1. One 26"x 54" door opening.

Wall Coverings

1. Faced insulated wall covering.

Observations

1. The room is protected by 64 lb of Halon 1301 which is located outside of the room on the main deck to the left of the door.
2. Two heads are located in the room; one directly over the diesel generator and another, one foot horizontally off of the far corner of the last set of wood storage shelves (closest to the center of the room).

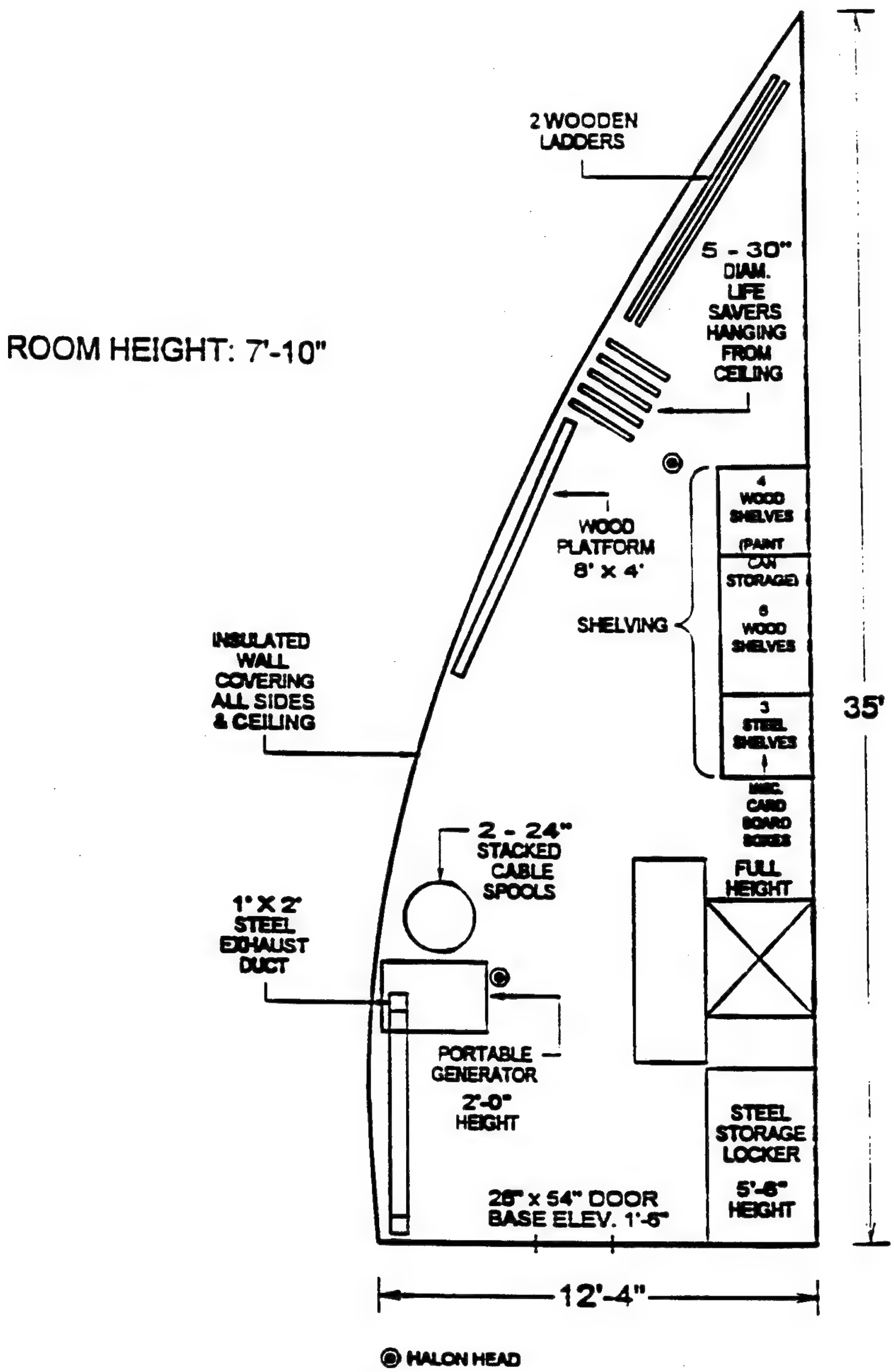

Fig. A1 - LCV 2003 Flammable Liquid Storage Room

Table A2. Survey Summary Chart

Vessel: LCU 1675

Compartment: Flammable Liquid Storage Room - See Figure

Room dimensions:

Length:	13'-2", 15'-6"
Width:	3'-6"
Main compartment height:	5'-3"
Bilge depth:	N/A
Overall height:	5'-3"

Potential hazards

1. Flammable liquids: Paints in closed and open 1 and 5 gallon cans; paint thinners; stripping agents; linseed oil; lubricating agents and paints in aerosol spray cans.
2. Combustibles: Rollers; brushes; joint tape; rags; cardboard boxes.
3. Propane cylinders

Openings

1. One 38"x 48" door opening.

Wall Coverings

1. Faced insulated wall covering.

Observations

1. The room is protected by 40 lb of Halon 1301. The cylinder is located in the space to the left of the door.
2. The room contains one head centered one foot behind the first steel partition wall.
3. Each partition wall has an opening accounting for approximately 50% of its surface area.
4. The two rear compartments had virtually no contents within them and as a rule usually don't.

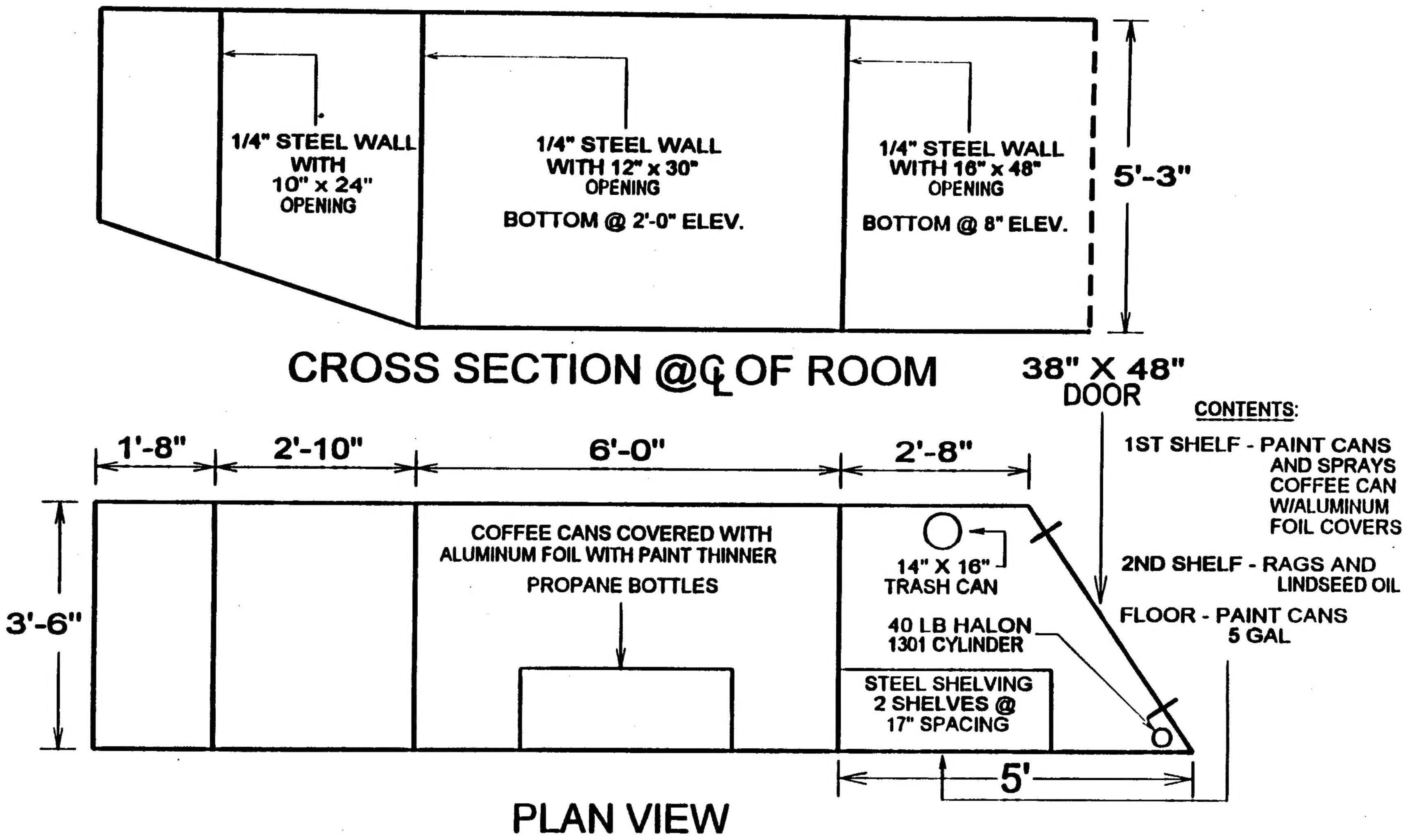

Fig. A2 - LCU 1675 Flammable Liquid Storage Room

Table A3. Survey Summary Chart

Vessel: LSV

Compartment: Flammable Liquid Storage Room - See Figure

Room dimensions:

Length:	11'-0"
Width:	10'-4"with a 6'-0" x 5'-0" extension along one length side.
Main compartment height:	11'-0"
Bilge depth:	N/A
Overall height:	11'-0"

Potential hazards

1. Flammable liquids: Paints in closed and open 1 and 5 gallon cans; paint thinners; stripping agents; linseed oil.
2. Combustibles: Rollers; brushes; joint tape; rags; cardboard boxes; wood pallets.

Openings

1. One 26"x 54" door opening.

Wall Coverings

1. Faced insulated wall covering.

Observations

1. The room contains an small metal paint locker which is protected by an in-cabinet 5 lb Halon 1301 system.
2. The room is protected by an 80 lb Halon 1301 system located within the room.
3. A heat detector is located in the center of the 11'-0" x 10'-4" section of the room.

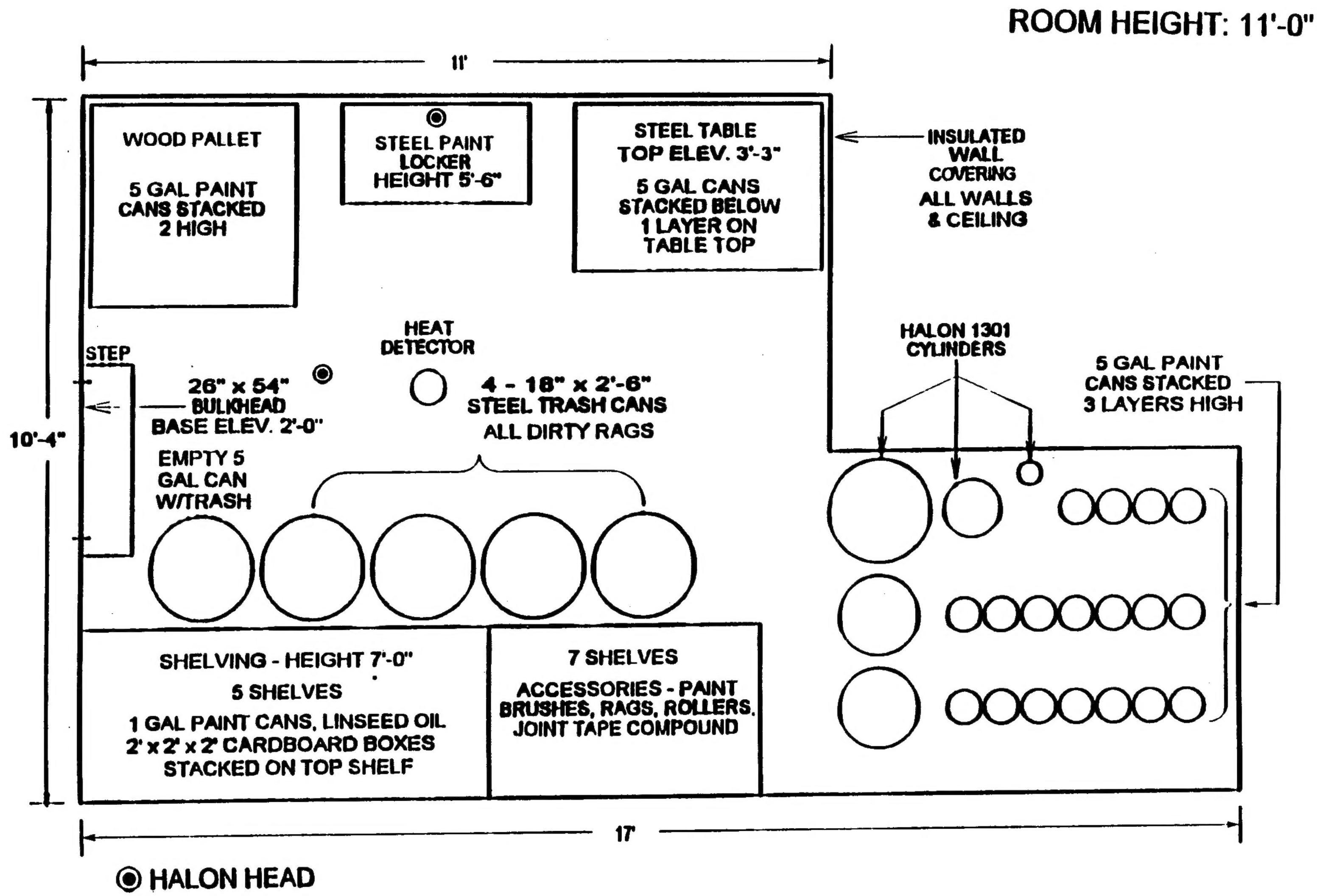

Fig. A3 - LSV Flammable Liquids Storage Room